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A PROJECTION OF THE EFFECTIVENESS AND COSTS OF A NATIONAL TAX ON SULFUR EMISSIONS

FINAL REPORT

Prepared for

Implementation Research Division
Environmental Protection Agency

by

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DISCLAIMER

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This project was under the direct supervision of Tayler H. Bingham with several individuals contributing to specific aspects of the research described in this report. Principal among these and their contributions are:

Philip C. Cooley	Model design and programming
Mark E. Fogel	Control costs and new technology options
Donald R. Johnston	Analysis of impact of tax on air quality
David A. LeSourd	Area source analysis
Allen K. Miedema	New technology analysis
Richard E. Paddock	Steam-electric power plant and sulfuric acid plant control costs
Mayrant Simons, Jr.	Petroleum refinery control costs
Macmillan M. Wisler	Smelter control costs

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A PROJECTION OF THE EFFECTIVENESS AND COSTS OF A NATIONAL TAX ON SULFUR EMISSIONS

Chapter 1: INTRODUCTION AND SUMMARY

1.1 Background

Writing in 1920, the British economist A. C. Pigou observed that London received only 12 percent of the available sunlight due to the smoke in the atmosphere from factory chimneys and that the smoke inflicted "a heavy uncharged loss on the community, in injury to buildings and vegetables, expenses for washing clothes and cleaning rooms, expenses for the provision of extra artificial light, and in many other ways."* Pigou identified the reason for the smoke as the difference between the private costs and the social costs of production. Industrialists, in producing consumer goods and services at minimum private costs also imposed an additional social cost on third parties since the value of clean air was not included as part of the costs of production. The assimilative capacity of the atmosphere was free to emitters. Consequently, industrialists had no incentive to install "smoke-preventing appliances," for the costs of such "appliances" would simply raise the costs of production, thus making the affected products less price-competitive.

Pigou advocated intervention by government to remove the divergence between social and private costs, specifically citing emissions taxes as a possible mechanism for removing the divergence. Today, more than half a century later, economists are reiterating the same basic recommendation. In particular, a tax on sulfur emissions has been proposed both by members of government and private citizens on the basis of the effectiveness of such a tax in reducing sulfur emissions to desirable levels at the smallest total cost to society. This study provides an initial examination of the effectiveness and costs of a uniform national tax on the major emitters of sulfur (or more exactly, sulfur compounds).

Since current legislative and political considerations, coupled with the still advancing state-of-the-art in sulfur oxide flue gas control techniques, make the implementation of such a tax unlikely before 1978, this study

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*A. C. Pigou, The Economics of Welfare. London: Macmillan and Co., Ltd., 1920, pp. 160-61.

is directed toward the goal of evaluating the potential costs and implicit reductions in emissions that would occur in the presence of various tax rates on sulfur emissions during that year. Though most of the results address the national impact of such a policy tool on each of five major sulfur emission source categories, some attention is also given to regional effects and to the intrafuel price effects of such a tax.

1.2 Effects of Sulfur Oxides

Sulfur is present in polluted atmospheres as a component of both particulate matter and gases. In particulate matter it may occur as a sulfate salt or as highly corrosive sulfuric acid. As a gaseous component, sulfur is present in hydrogen sulfide, mercaptans, and sulfur oxides.

The principal physiological effect of sulfur dioxide (SO_2) and sulfuric acid (H_2SO_4) is is bronchoconstriction, leading to an increase in airway resistance. Epidemiological studies of acute air pollution episodes have shown a significant association between excess mortality and morbidity and elevated SO_2 concentrations with associated particulate matter. People with preexisting diseases of the heart and lungs are particularly vulnerable to the effects of SO_2.

Nonhealth effects of sulfur compounds include reduction of visibility by suspended sulfate and sulfuric acid particles, accelerated corrosion of metals at relative humidities greater than 70 percent, and deterioration of limestone, marble, roofing slate, and mortar. Textile fibers are damaged, fabrics fade, leather loses its strength, and paper is embrittled in the presence of SO_2. Sulfur dioxide and H_2SO_4 at sufficient concentration for an appropriate length of time also cause injury to ornamental and economic crops.

Based on an examination of available data on the relationship between concentration and the occurrence of adverse effects, the Environmental Protection Agency (EPA) has set National Ambient Air Quality Standards for SO_2. By maintaining sulfur oxides concentrations at or below those specified in the standards, it is hoped that adverse effects will be avoided.

To achieve the National Ambient Air Quality Standards, several States have developed implementation plans that rely principally on regulation of sources, specifying such things as the sulfur content of fuels and allowable SO emissions. This research evaluates the effectiveness of a national tax on sulfur emissions either as an alternative or as a supplemental strategy to achieve the National Ambient Air Quality Standards for sulfur oxides.*

1.3 The Concept of a Tax on Sulfur Emissions

Emissions taxes are government-imposed prices on the discharges of pollutants to the atmosphere. Their purpose may not be to raise revenue, although they would have that effect; rather their purpose should be to encourage the equalization of both the marginal costs and the marginal benefits of using the assimilative capacity of the atmosphere or to induce the attainment of desired air quality levels at minimum cost. The costs of emission reductions in the presence of a tax would be internalized to the firm and typically incorporated to some degree in product prices. This would force producers and consumers of that product to pay directly the costs of residuals treatment and disposal. This situation contrasts with that of present air pollution externalities, in which these costs are passed along in the form of social costs to all pollution receptor groups.

In general, polluting sources can be expected to control emissions to the point where the incremental cost of removing the last unit of effluent from the process off-gases equals the tax rate. Taxes would then be paid on any uncontrolled discharges of pollutants to the atmosphere. The existence of these tax payments, which are costs to the firm, provide a persistent incentive to seek new, more cost-effective ways to control waste discharges.

1.4 Approach

This study of a tax on sulfur emissions, applied on a national basis, uses a comparative statics approach to project emissions in the absence of air pollution regulations (except the New Source Performance Standards) and emissions and costs under several alternative tax rates for 1978.

The study is confined to five major sources of sulfur emissions which account for over 90 percent of all estimated sulfur emissions (table 1). These sources range from steam-electric plants which contribute

*Note that it is quite reasonable for either Federal or regional pollution control authorities to consider the addition of a sulfur tax to present regulations. Such an approach would have two effects: first, it would provide an additional incentive for plants to meet already existing regulations; second, it would retain at least some of the cost-effectiveness properties of a tax while assuming a minimum level of control (under the regulation) applicable to all sources.

Table 1. Major sources of sulfur emissions

Emissions source	Percent of total
Fuel combustion	
Steam-electric	50.6
Area sources*	22.8
Industrial process	
Primary nonferrous smelters	11.7
Petroleum refineries	6.3
Sulfuric acid	1.8
Total	93.2

*Space heating and industrial boilers.

Source: Nationwide Inventory of Air Pollutant Emissions 1968. Raleigh, N. C.: NAPCA, August 1970.

over 50 percent of total sulfur emissions, to sulfuric acid plants which account for less than 2 percent of the total sulfur emissions.

An inventory of these sources in 1970 was developed which contains data on plant capacities and the process configurations necessary to estimate emissions and control costs. This inventory was based on previous inventories used by RTI and supplemented with current information obtained from EPA and from trade sources to make it applicable to 1970. In spite of these efforts, some errors and omissions in the inventory are possible. It is doubtful, however, that they would be significant enough to affect the projected effectiveness or costs of the tax on sulfur emissions on a national level. Because the tax was to be analyzed for 1978, projections of industry growth were employed. New plants were added to the inventory on the basis of available projections of industry growth and observed trends in plant size and process types.

Sulfur emission control alternatives were identified and their costs were estimated from data presented in previous studies for EPA, based on private communications with EPA industry specialists, or developed by RTI. The control or abatement costs were aggregated from estimates specific to source location, plant capacity, and process configuration. All control costs are on an annualized basis.

The number of control alternatives costed for each source depended on available data. In some cases, only two control alternatives appeared feasible. In the case of steam-electric utilities, about 1,000 combinations of fuels, fuel origin, sulfur content, and flue gas desulfurization alternatives were costed for each utility.

A computer model was developed to determine each plant's behavior under a tax, compute emissions and costs, sum the results over the industry, and print the results in tabular form. It is assumed that emissions sources will minimize the sum of the costs of emissions reductions and tax outlays by selecting the level of emissions reductions where the net marginal costs of these reductions (MC_{ER}), after allowing for the sale (if any) of byproducts, equals the tax rate (TX). That is, MC_{ER} = TX. At this level of emissions reductions, the total pollution-related costs to the source (i.e., annualized control costs plus tax payments) are minimized. All sulfur values presented in this report are in terms of sulfur, not sulfur dioxide (SO_2), which is 50 percent sulfur.

This study has followed the convention used in the Cost of Clean Air and many other EPA-sponsored studies in using non-tax-adjusted cost estimates. It is recognized, however, that (because tax payments on sulfur emissions would be tax deductible expenses) the effective tax rate is overstated by the marginal percentage rate of corporate income taxes faced by the firm. This argument, of course, assumes that the firm has enough profits for the tax payments to be a usable tax deduction. It is also the case, however, that all of the abatement costs are overestimated by at least the same factor since all variable costs associated with pollution control are also fully tax deductible and since the capital costs of pollution control devices are subject to special accelerated depreciation schemes. In effect, this study assumes that the tax rate and the pollution control

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*Cost of Clean Air, 1973, "Annual Report of the Administrator of the Environmental Protection Agency to the Congress of the United States." Subsequent references to Cost of Clean Air mean any issue of the annual report.

costs are overstated by approximately the same factor. As a result the projected emissions reductions would be unchanged by including corporate income tax considerations since both the marginal costs of emissions reductions (MC_{ER}) and the tax rate (TX) can be rescaled by a constant fraction to derive approximations of the net control costs and net tax rate. See appendix F for a discussion of the problems and biases implicit in these assumptions.

Other alterations in the relative price of pollution control hardware--due to the issuance of municipal or State revenue bonds to subsidize corporate financing of pollution control devices, to preferential exemptions from property taxes on pollution control gear, and to pollution control related State income tax preferences--are likely to enhance further the attractiveness of control hardware over tax payments. These, coupled with the effects of the Federal corporatetax structure, are, in RTI's judgment, likely to cause some understatement in the estimated emissions reductions that would be achieved at the various tax rates projected in this report. The magnitude of that understatement, though difficult to evaluate for 1978 in view of continually emerging tax preferences on pollution control gear at the local level, is not likely to have caused large errors in predicted emissions reductions.

1.5 Assumptions, Limitations, and Capabilities

Several assumptions and limitations are present in this study regarding the data inputs and methodology employed.

It has been assumed that the emissions control alternatives identified in this study will be available in time for installation and operation by 1978. If supply conditions delay their applications, the effectiveness of the tax for 1978 will be less than, and the costs greater than, those projected.

Because of the lack of data and the scope of this study, only a limited number of control alternatives have been evaluated for each source. Most of these alternatives have high control efficiencies (80 to 99 percent). It is likely, however, that other control alternatives, including process changes, would be induced with an emissions tax. This would tend to increase the projected effectiveness of the tax in motivating emissions reductions and, further, it would tend to lower costs from those presented in this study.

The dynamics of fossil-fuel supply and prices have not been explored to the extent possible. These factors will play a critical role in influencing the effectiveness and the costs, not only of the tax but also of the regulatory approaches to achieving emissions reductions. However, a preliminary analysis has been conducted of how the projected effectiveness and costs of the tax may be influenced by future fuels supply.

The most obvious comparison to this report is the annually published Cost of Clean Air. Any reader making comparisons should be alert to some critical differences between the underlying assumptions and methodologies of the two reports. The most obvious difference is that the Cost of Clean Air shows total costs for reductions in sulfur dioxide emissions while this report shows costs for sulfur, which constitutes one-half of the equivalent mass of sulfur dioxide. Secondly, this study accommodates not just one but several control options for every emissions source. For fuel combustion sources, these options include: fuel switching among several sulfur content fuel types, distinguished by location of origin; three separate flue gas control hardware options; and emissions tax payments. For other industrial sources, the control options include choices between various hardware or process changes for each process source and tax payments. The Cost of Clean Air, on the other hand, generally has taken an inflexible approach in imposing a control option on specific plants and totaling up the resultant estimates. Furthermore, where fuel switching has been considered only, the Cost of Clean Air has incorporated a simple, low sulfur fuel cost premium to derive the cost of the alternative fuel. The model of this study was more detailed in that fuel transportation costs and supply considerations were built into the simulated array of fuel options available to each plant. A final consideration is that RTI attempted to incorporate current refinements in the estimates of control hardware costs. In some cases, these estimates (reported in appendixes A through D) differed substantially from those used in the Cost of Clean Air. In summary, the control costs projected here are not fully comparable with those reported in the Cost of Clean Air owing, mainly, to different methods of deriving low sulfur fuel prices, to the wider array of control choices available to plants, and to the incorporation of more recent estimates of control hardware costs. Despite these differences, however, the interested reader will note that the cost estimate of the two reports, after appropriate adjustments for the units difference sulfur versus sulfur dioxide), are within the same order of magnitude,

1.6 Summary of Findings

Based on the results of the research presented in this study, it appears that a national tax on the sulfur emissions of the five major sources of this pollutant would be an effective means of inducing emissions reductions. Specifically, table 2 shows the reductions, costs, and tax payments projected for selected tax rates.

Although no direct comparisons have been developed here between the costs under a system of emissions standards and those under a system of emissions taxes, the aggregate cost to the Nation of emissions reductions with a tax will be no higher than those under an emissions standards approach to air quality management for a given reduction in emissions.* In all likelihood, these costs under a tax would be substantially less

Table 2. Summary of the projected effectiveness and costs of a national tax on the major sources of sulfur emissions--1978

Tax rate (cents per pound of sulfur emissions)	Percentage reductions from unconstrained emission levels*	Total annual cost (billions)	Annualized control cost (billions)	Annual. tax payment (billions)
5	53	$1.8	$0.9	$0.9
10	74	2.7	1.7	1.0
15	78	3.4	2.1	1.3
20	80	3.9	2.4	1.6
25	83	4.4	2.8	1.7
30	85	4.9	3.0	1.9

*The single exception is the assumption that the New Source Performance Standards are implemented regardless of the tax rate.

Source: Research Triangle Institute.

*It is possible, in fact likely, that the sum of tax payments and control costs would be higher under an emissions tax policy than under standards. The total cost to society, however, must not include emissions tax payments since they simply represent income redistributions.

than those under an emissions standards approach because of the efficiency inducing properties of such a tax. A comparison of the emissions and cost data presented in the Cost of Clean Air with emissions and control cost data presented in this report under a tax strategy is presented in table 3. As discussed above, the reader should not conclude that the only basis for the differences in results between the Cost of Clean Air and this study is due to the relative efficiencies of taxes and regulations, since different methodologies were used to develop the cost of control estimates.

Under either a regulatory or tax approach, reductions in the emission of other pollutants may be achieved when controlling sulfur oxide emissions. This is due to the technology of the control alternatives. For example, in applying flue gas desulfurization technologies to sulfur oxide discharges, particulate emissions are usually reduced also. Similarly, switching from coal to oil may also reduce particulate as well as sulfur emissions. This added benefit has not been included in this study.

An emissions tax will significantly increase the demand for low sulfur fuels since they constitute a particularly attractive means of reducing sulfur emissions caused by fuel combustion. If the long-run supply of these

Table 3. Comparison of Costs of Clean Air and emissions tax results--1978

Source	Cost of Clean Air data'				Emissions tax data:			
	Uncontrolled emissions (thousand tons of sulfur)	Reductions in Emissions (thousand tons of sulfur)	Reductions in Emissions (percent)	Annualized control costs (million dollars)	Uncontrolled emissions (thousand tons of sulfur)	Reductions in emissions (thousand tons of sulfur)	Annualized control costs (million dollars)	Required tax rate to induce control (cents per pound of sulfur emissions
Steam-electric utilities	14.075	11,445	81.3	$1,860	11,396	9.265	$1,600	18
Area sources	3,887	3,070	79.0	1,342	5,678	4,486	500	20
Petroleum refineries	2,202	2,153	97.7	34	772	754	>27	>30
Sulfuric acid plants	929	642	69.1	29	385	266	33	10
Primary non-ferrous smelter	2,541	1,990	78.3	184	1,651	1,293	50	4

*Cost of Clean Air, Environmental Protection Agency, Washington D.C., 1973.
†Developed from data presented in this study for same percent reductions in emissions as implied in the Cost of Clean Air.

fuels is inelastic, prices may increase fairly substantially. This study attempts to incorporate (into the determination of those fuel price projections) supply considerations that, at this juncture, seem reasonable. The reader is referred to section 3.2 and appendix A for more detailed discussions of these assumptions.

Though it is difficult to place confidence limits on the estimates of control costs used in this study, it is perhaps useful to distinguish the elements of control costs along with RTI's overall confidence in the estimated costs for those components. In general, the estimates of initial purchase costs of pollution control gear are quite good; estimation errors are on the order of ± 10 percent. Equipment installations costs, on the other hand, may vary by as much as 100 percent about the mean estimates. Among annualized costs, the errors in annualized cost are jointly determined by the above-mentioned capital cost estimates and potential errors in the discount rate. Operating, maintenance, and replacement costs consist of labor, power, water, and chemicals costs; all of these are subject to small variations (on the order of ± 10 percent) in the short run. A rough weighting of these estimates of error according to the share of each component in total annualized costs yields an average range of error in individual estimates of ± 16 to 20 percent.

For the industrial sources, use of alternative market values for recovered sulfur and sulfuric acid of ± 100 percent from the projected 1978 values ($10 per ton) is estimated to have little impact on the effectiveness and costs of the tax for most sources. Likewise, control cost deviations of ± 20 percent do not significantly alter the results of the study. It is likely, however, that the results are sensitive to the number of available control alternatives. If more alternatives were available to the industrial sources whose current control options manifest low removal efficiencies, the costs of the tax for these sources would be less than those projected, and the effectiveness greater at low-to-medium (5- to 15-cent) tax rates.

Chapter 2: THE APPLICATION OF EMISSIONS TAXES FOR POLLUTION CONTROL

2.1 Introduction

The problem of air pollution, viewed from an economic perspective, is one of overutilization of a scarce resource. The overutilized resource is the waste removal capacity of the air; that is, the capacity of the air to assimilate unwanted byproducts of production and consumption without imposing damages on such receptors as people and plant life. Historically, clean air has been a "free good", with more than enough available to saturate demand. However, the accelerated use of the atmosphere as a low-cost means of waste (or residuals) disposal has created health, property, and esthetic damages. Reduction in the damages inflicted upon society by a polluted atmosphere will require rationing of the use of the atmosphere for residuals disposal.

Residuals charges are a market-type mechanism for rationing environmental resources. Emissions taxes, one type of such charges, have been proposed by an increasing number of people concerned about the quality of the environment and the efficiency and costs of other, nonmarket types of strategies. This chapter briefly examines the rationale behind such charges with reference to a tax on sulfur emissions.

2.2 Air Quality and Market Failure

Most economic goods are rationed through a market process in which product prices reflect society's tastes and desires and in which costs reflect productive capabilities. This market process is generally regarded as a reasonably efficient means of resource rationing and allocation. Clean air, however, has no effective market. Even though one may desire clean air, there is no market where this preference can be registered. The result is the overutilization of the atmosphere for one service, residuals disposal, thereby transferring to society as a whole the costs of residuals disposal rather than incorporating these costs as a part of product costs and price. In this situation, an external diseconomy is said to exist. Since the costs of residuals disposal are not "internalized," product prices do not reflect alternative uses of the atmosphere. As a result, too many private goods whose production generates residuals and too few public goods such as clean air are produced. If the value to society of the atmosphere for purposes other than residuals discharges could be made to bear directly on discharging activities, polluters would reduce their discharges to the atmosphere.

Unfortunately, two conditions preclude the existence of an effective market for clean air. First is the absence of well-defined and enforceable property rights in the atmosphere. Second is the public-goods nature of clear air.

Of the two conditions, the public-goods nature of clean air is the primary reason for the lack of a market for clean air, since the creation of property rights in the atmosphere has limited practical applicability.* Public goods are goods that if supplied to one individual (e.g., national defense) are available to all. In the case of clean air, if air pollution is reduced in response to a "demand" on the part of some individuals, pollution will be reduced for all. Thus, appropriate aggregate information and responses needed to generate a market for public goods are generally lacking.

Nevertheless, because of the desirability of charging for the use of scarce resources, such as the assimilative capacity of the air, other pricing mechanisms are available in the absence of markets. The most often proposed alternative is the use of emissions taxes.

2.3 Emissions Taxes

Emissions taxes are a form of government intervention; the implicit rationale for them is that property rights in the atmosphere are vested in the public with the government acting as agent for the public interest by rationing the use of the atmosphere for waste disposal.

When prices (taxes) are placed on the use of the atmosphere for discharging the unwanted byproducts of production (e.g., sulfur oxides), emitters have an incentive to economize on their use of the environment just as relative resource prices currently guide decisionmakers to the most efficient use and combinations of land, labor, and capital. The abatement analysis burden is placed on corporate management which is,

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*A. M. Freeman, III, The Economics of Pollution Control and Environmental Quality, General Learning Press, 1971, pp. 1-27.

or will become, more knowledgeable regarding the cost-effectiveness of various control alternatives than government officials who are likely to have only incomplete information. Conceptually, at least, emissions taxes could be adjusted to the time of day, season, weather, or economic conditions in order to reflect the variable nature of damages.

In the presence of an emissions tax, polluters will adjust their individual level of control so that the last ton of emission reduction from all sources imposes the same cost on each source. This is significant for it means that the reduction in total emissions is achieved at the least amount of the control cost.

Furthermore, the emissions tax provides a continuing incentive for firms to seek newer and more efficient means of controlling their discharge and to avoid judicial delay tactics. These desirable tendencies are not usually encouraged under a system of emissions standards.

With the imposition of an emissions tax, polluters can be expected to pursue the least-cost means of residuals management. These costs can be conveniently divided into two components: control costs and emissions tax payments. The sum of these two costs--after adjusting for the effect of income taxes--will be minimized. The extent to which emissions are controlled will depend on the relative cost of control and the tax rate. This decision analysis can also be examined on a per unit basis.

For example, as shown in figure 1, assume that before a tax is levied on emissions, the plant is emitting E tons per year. A tax (T) per ton of emissions will induce the plant to effect emissions reductions until the margin. cost of doing so equals the tax rate; it will produce A units of pollution control per year or, to put it another way, it will reduce its emissions from E to E-A. The control cost of emissions reductions will be the area 0AB. The tax bill will be T(E-A); i.e., the tax rate times the flow of remaining emissions, whose product is equal to the area ABCE.

Ideally, the tax rate should be set at a level sufficient to induce reductions in emissions to a rate where the incremental damages of pollution equals the incremental cost of emissions reductions (see fig. 2). However, the application of emissions taxes to problems of air quality is not dependent on the availability of reliable information regarding damages from air pollution. Because air quality goals have been established by

EPA, emissions reductions necessary to achieve these air quality standards can be induced by emissions taxes. The remainder of the study explores the relationships among alternative emission tax rates, control costs, and resulting emissions.

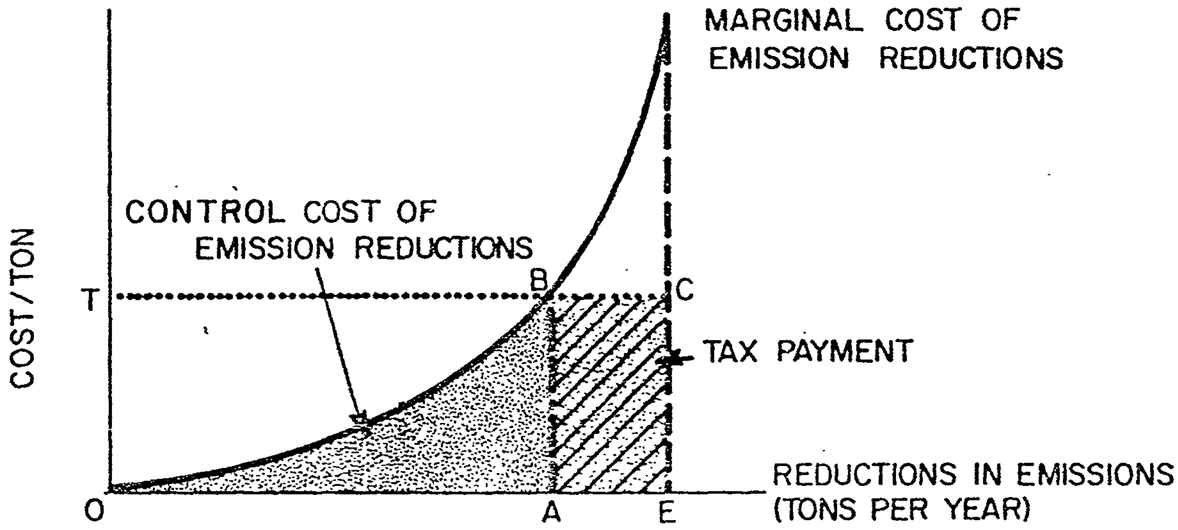

Figure 1. Emission source behavior in response to a tax.

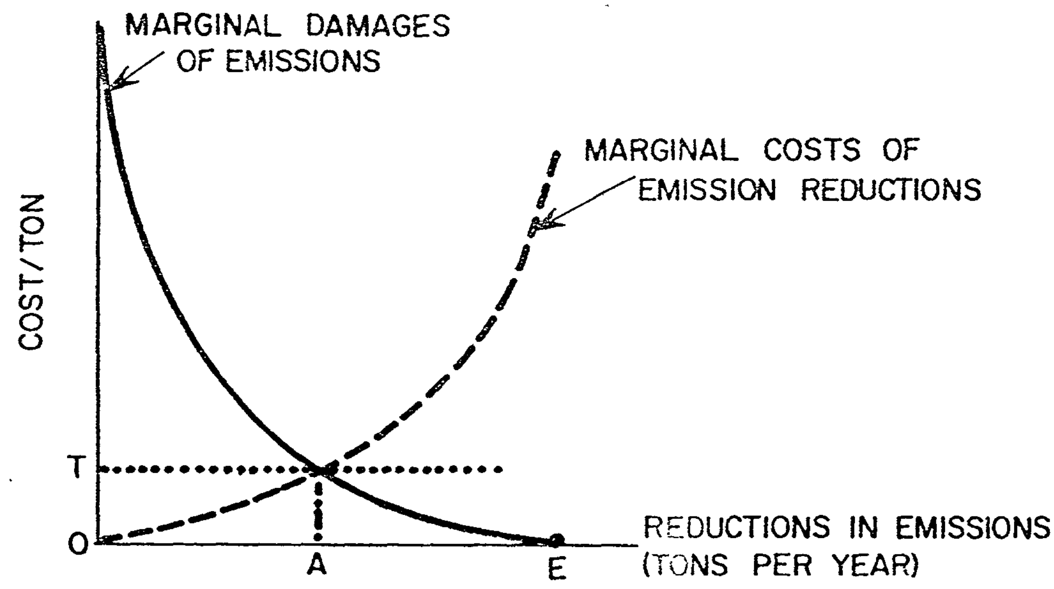

Figure 2. Socially optimal level of emissions.

Chapter 3: ANALYSIS OF THE EFFECTIVENESS AND COSTS OF A TAX ON SULFUR EMISSIONS

3.1 Introduction

To estimate the probable effectiveness and costs that would result from implementation of a tax on sulfur released into the atmosphere, an emissions response model was developed and applied to three industrial process sources, steam-electric utilities, and area heating sources. When combined, these sources account for over 90 percent of U.S. sulfur emissions. The model calculates controlled emissions and costs at specified tax rates for each plant and aggregates each industry for the Nation as a whole. Controlled emissions and costs for area sources are also estimated and added to provide national totals. This analysis was performed for the year 1978, 5 years hence, on the assumption that the projected control systems will be availble and could be installed by then. The factors used and the results of the analysis are given below.

3.2 The Emissions Response Model

The procedure of this study is to approximate, heuristically, the individual plant's reponse to an emissions tax. This is accomplished by the use of an emissions response model developed for this study. Throughout the analysis several simplifying assumptions are made regarding plant or source operation regardless of classification. Those assumptions are:

(1) That product output at all existing point sources remains constant; no plants go out of business or curtail production in response to emissions control taxes;

(2) That the plant manager chooses the combination of emissions tax payments and emissions control options in such a way that his total outlay is minimized;

(3) That expected annualized control costs are sufficiently approximated by previous studies for EPA cited herein (and discussed in detail in appendixes A through D);

(4) That the finite number of control options studied here are representative of those that producers will face in 1978; i.e., that no extraordinary technical changes in sulfur oxide control technology will occur during the next 5 years.

The remainder of this section discusses the assumptions and methodology for each of the broad emission source categories: fuel combustion sources and industrial process sources.

3.2.1 Fuel Combustion Sources

The two broad types of fuel combustion sources are steam-electric power plants and area sources; i.e., commercial, residential, and industrial space heating. Both of these sources are assumed to have the option of fuel switching; i.e., changing from one fuel type to another or from one sulfur content to another. Only power plants are assumed to have the option of removing entrained sulfur from the carrier gas. The following paragraphs first discuss the assumptions regarding fuel availability supplies and prices (sec. 3.2.1.1). With that background, the next sections summarize the additional assumptions and methodology involved in deriving the cost-minimizing control options for steam-electric power plants (sec. 3.2.1.2) and area sources (sec. 3.2.1.3). More detailed discussions are presented in appendix A.

3.2.1.1 Fuel Supplies and Prices

3.2.1.1.1 Fuel Supplies. Because available fuel supplies are not uniformly distributed with respect to sulfur content, Btu value, and location, it has been necessary to explicitly incorporate consideration of these parameters in this study. The approach employed for each fuel is presented below.

a. Coal. The 1978 maximum production of coal was projected within each of seven designated coal-producing basins by sulfur contents. The method of projection relied on a technique developed by the MITRE Corporation. The projections involve the use of a growth rate within each of the 7 basins for each of 9 sulfur content groupings. Those projections yield 63 (9 sulfur contents times 7 basins) estimates of maximum commercial bituminous coal production.

The seven basins were further subdivided according to the 19 coal-producing districts defined by the U.S. Department of Interior using projected regional proportions developed by Battelle. The resulting projections comprised 171 maximum supply estimates for coal (19 districts times 9 sulfur contents). The Btu content of these coals were assumed invariant within each of the 19 districts; the Btu values were averages for each region reported by the MITRE Corporation. Initially prices of the 171 fuels at their origins were adapted from the Battelle study. Subsequently they were adjusted in a manner discussed below (sec. 3.2.1.1.2). Because some sulfur content coals are not available within all regions, there were 21 empty cells in the fuel price and supply matrices. Consequently, the total number of coals, distinguished by district of origin and by sulfur content, is 150. To estimate the delivered price of these coals, RTI employed the transportation cost matrix developed by Battelle. That matrix provides estimates of shipping costs from the 19 coal regions to 50 destinations.

By adding those transportation costs to the coal prices at their origin for each of the 50 destinations, tables of delivered coal prices were developed. Each existing plant or source was then associated with one of those 50 destinations; this determined which of the 50 delivered-price vectors was relevant to a particular decision unit. Those vectors of delivered coal prices then become part of the decision unit's control costs.

b. Residual Oil. Only about one-third of annual U.S. consumption of residual oil is domestically produced. The maximum expected supplies of these domestic residual oils were projected for 1978 by Petroleum Administration for Defense (PAD) districts in a previous study by the MITRE Corporation. Those projected supplies were then allocated among the 12 oil-producing districts defined by the U.S. Department of the Interior, again on the basis of the distributions developed by Battelle. The result was a matrix of 48 domestically supplied oils (12 origins times 5 sulfur contents minus 12 empty cells). In addition, imported residual oil was also assumed available at four ports of entry (east coast, gulf coast, west coast, Great Lakes). Wellhead or POE prices were adapted from the Battelle study. A matrix of transportation prices developed by Battelle was used to develop estimates of delivered prices. These vectors of delivered oil prices, plus the coal prices determined as described above, are the fuel cost-sulfur content alternatives.

c. Natural Gas. For utilities, the supply of gas was assumed to be perfectly elastic to current users up to the quantities currently used and to be perfectly inelastic above those quantities. Therefore, no utilities were allowed to switch to gas or to increase gas consumption. For area sources, the market share of gas was assumed to remain constant at 1970 proportions among individual States. All gas prices assumed were those developed by Battelle.

d. Distillate Oil. Distillate oil, used primarily as a source of energy for area sources, was assumed to be unlimited in supply at prices projected by Battelle.

3.2.1.1.2 Fuel Price Adjustment. The first iteration of the model at a zero tax implied that the maximum projected supplies of coal and residual oil would be exceeded for some of the 198 domestically produced fuels. The most obvious way to handle this problem was to incorporate the 198 supply constraints while simultaneously minimizing the control costs associated with all fuel combustion sources. That approach, however, would have implied a major linear programing effort beyond the resource constraints of this project. The alternative chosen here was heuristic. Whenever the demand for a specific coal exceeded the maximum predicted supply, its price was arbitrarily increased by a small amount (generally on the order of 5 percent of base point prices). The entire model was then iterated again. This process was continued until the total domestic demand for coal was smaller than the corresponding total projected domestic supplies. The implicit assumption here of domestic self-sufficiency of coal appears warranted in view of the large U.S. reserves of coal, and historical consumption patterns.

For residual oil, demand exceeded domestic supply. However, additional supplies were assumed to be available from foreign suppliers at given prices. The sensitivity of the projected responses of the utilities to the assumed oil prices was, however, evaluated (see chapter 4). The general effect of this method of approximating price responses is likely to induce a downward bias in the costs of switching to low-sulfur fuels. Consequently, one could expect more control hardware applications than the model predicts.

3.2.1.2 Steam-Electric Power Plants. Each existing power plant was identified and its output, size, and operating characteristics recorded. Those plants were assumed to face three hardware options for the removal of sulfur from the combustion gases, each with an assumed potential control efficiency. They are the dry limestone, wet limestone, and magnesia scrubbing processes. The annualized costs of those options were intended to approximate the annual outlays whose present value over the firm's planning horizon equals the expected investment cost plus the discounted present value of their associated operating costs. Estimates of those costs were developed as functions of the sulfur content of the fuel, the megawatt capacities of the boilers at the plant, and the annual output at the plant. The cost estimating equations, formulated in previous studies for EPA, were adapted for this study. New power plants were projected to come on line in accordance with the National Coal Association listing of conventional steam-electric plants that are planned or under construction during 1971-1977.* These plants were assumed to adhere to the New Source Performance Standards. Consequently, new coal- or oil-fired plants were expected to install either a wet limestone or magnesia scrubbing system. The costs of those systems were not included in the total costs of control in this study.

Each plant then was assumed to minimize the total annual outlays of three components of costs: emissions tax payments, annualized abatement costs, and delivered fuel costs. For each tax rate considered, the computer simulation model scanned the sum of these three costs for every fuel type by sulfur content and for every control hardware option. About 1,000 alternatives exist for each source. The combination of hardware, fuel type, and emissions tax payments that minimized total outlay was the predicted response of the plant. The costs of these responses and the corresponding reductions in sulfur emissions at various tax rates per unit of sulfur emissions were aggregated over all plants.

3.2.1.3 Area Sources. Area sources comprise residential, commercial, and industrial fuel consumers. Since the available statistics relating numbers, size, and distribution of these heating units are either scant or nonexistent, this study attempted to simulate the response of individual emitters by analyzing each State as an aggregate. Though this approach has rather obvious drawbacks, the predicted behavioral response to the emissions taxes is felt to be a reasonable first approximation.

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*National Coal Association, Steam-Electric Plant Factors, 1969. Washington: National Coal Association, 1969, table 4.

The details of RTI's approach for an individual State are as follows. First, the percentages of total Btu input from coal, residual oil, natural gas, and distillate oil for each of the three area sources were determined for each State from published sources. Also, the absolute values of those fuel consumption rates for 1970 were recorded by State. Then the projected demands for 1978 were developed by applying separate growth rates to 1970 demands. No hardware control options were allowed for area sources. Further, among area sources only commercial and industrial users were allowed fuel switching.

a. Residential Sources. Since residential sources consume only natural gas and distillate oil, it was assumed that they did not switch to alternative fuels. It was further assumed that the residential fuel market shares accounted for by those two fuels remained constant over time. The growth rates applied to the 1970 State consumption rates were the projected State population growth rates published in the Survey of Current Business. Residential sources were then presumed to pay an emissions tax based on the sulfur content of those respective fuels. It is recognized that this is a rough first approximation that assumes demand is affected only by population growth and not by changes in the relative prices of distillate (because of the sulfur tax). If the demand for nonelectric home heating is relatively inelastic and if the supplies of natural gas are also quite limited, these assumptions are not likely to have caused serious prediction errors.

b. Commercial and Industrial Sources. Commercial and industrial emission source control options *were* assumed to be identical. The 1970 shares of total heat input accounted for by natural gas and by distillate oil among these sources were projected to remain stable through 1978. Absolute consumption values for each State were developed by applying the projected growth rate in overall national employment.

The proportion of heat input accounted for by residual oil and coal among commercial and industrial sources within a State was also assumed fixed at the 1970 proportion; but the relative shares of those two fuels within their jointly held market share was not.

The annualized cost whose present value was assumed to approximate the outlay necessary to install the coal-to-residual-oil-boiler conversion units was $11 per billion Btu.

The total outlays that commercial and industrial boilers are assumed to minimize, then, are the sum of the emissions tax and fuel costs of natural gas and distillate oil consumption--over which they have no control since the market shares accounted for by those two fuels remain constant--and the emissions tax, the fuel costs, and the boiler conversion costs of residual oil and coal consumption.

Once again it is clear that many complicated interrelationships have been rather quickly simplified: relative price sensitivities among fuels were not built in for natural gas and distillate oils vis-a-vis the aggregate of residual oil and coal consumption; growth trends were not developed on a State-by-State basis; no allowance was made for flue gas cleaning which may be feasible for large industrial sources; and all commercial-industrial sources in a State were forced to consume their present residual oil and coal heat inputs as either one or the other; i.e., no variable shares were allowed between these two fuels. Given sufficient data, these many analytical refinements might have been justifiable, but it was felt that the paucity of accurate information about these sources and their operating characteristics simply did not warrant attempts to build them in for this study. Yet, it was felt that the analysis did reflect a reasonable first approximation of the national emissions reductions that a sulfur tax would evoke from those area sources.

3.2.2 Industrial Process Sources

Industrial process sources of sulfur emissions comprise three industrial groupings: petroleum refineries (appendix E), sulfuric acid plants (appendix C), and primary nonferrous smelters (appendix D). The general approach for all of these sources was to determine hardware alternatives for sulfur oxide control and to annualize the cost of those installations. The individual plant's response to a tax was assumed to follow the cost-minimizing hypothesis. Whenever the total annual tax payments on the portion of emissions that were preventable with one of the hardware control options exceeded the annualized cost of that option, the plant was assumed to implement the control practice. Some of the details of this approach are discussed below for each major process source category.

3.2.2.1 Petroleum Refineries. The three major sources of refinery emissions are catalyst regenerators, Claus sulfur recovery plants, and fuel combustion sources. Approximately 13 percent of the sulfur content of crude oil processed at the plant is emitted from these three sources. The remainder is either recovered, emitted to waterways, or retained in marketed petroleum products.

The control option that was presumed most feasible for the control of emissions from catalyst regenerators was hydrodesulfurization of the catalytic cracker feedstock. This process essentially allows conversion of some of the sulfur in the feedstock to elemental sulfur. Each existing refinery in the United States was identified according to the type of catalyst regenerator in operation at the plant; then annualized costs of the hydrodesulfurization process were estimated according to several refinery capacities.

A refinery may or may not have a Claus plant, essentially a process that is used to convert hydrogen sulfide (H_2S) bearing refinery off-gases to elemental sulfur. If a refinery has no Claus plant, the H_2S stream is flared to the atmosphere resulting in substantial SO_2 emissions.

Each existing plant was then identified in terms of the type of catalyst regeneration it had in place and according to whether it had a Claus plant. The availability of EPA-estimated sulfur emission factors then facilitated an estimate of current emissions at each refinery.

The computer model simulated each refinery's response to an emissions tax in the following way. First, if the specific refinery's capacity did not correspond exactly to those for which control costs were estimated, interpolation was used. Then, sulfur emissions estimates were developed for these refinery sources from the emission factors and from estimates of refinery throughput. At each tax rate, total annual emissions tax payments associated with each of the three emissions sources were compared to the annualized cost of achieving some percentage reduction in those tax payments. If those costs were smaller than the associated tax savings, the refinery was projected to implement the subject control option.

This procedure resulted in aggregated estimates of abatement costs, of tax payments, and of emissions reductions across all three major emissions sources at any given refinery for each projected tax rate. Further aggregation across refineries yielded the industry emissions response curve for different levels of total abatement costs and for different sulfur tax rates or, identically, for different marginal costs of emissions reduction.

3.2.2.2 Sulfuric Acid Plants. Sulfuric acid plants emit sulfur in two forms: (1) as a gas, sulfur dioxide (SO_2), and (2) as an acid mist. The former results from incomplete absorption of SO_2 during the production process; the latter emerges from the absorption tower in the process off-gases. The two control techniques that were considered for gaseous emissions were the dual absorption and the sodium sulfite scrubbing processes. Their expected annualized costs are reported in appendix C.

For both gaseous and mist effluents, total potential emissions were computed using EPA estimates of emission factors and estimates of each plant's production of acid. By comparing total implied emissions tax payments under various tax rates to the annualized costs of control for each type of effluent, RTI projected whether or not abatement practices would be implemented. The choice criterion was whether or not the tax savings exceeded the annualized costs of the control option.

Total costs of tax payments, plus abatement costs, less the value of recovered sulfur were then aggregated for each plant and also across plants for the industry. The resulting projections of emissions reductions versus total annualized costs and versus marginal costs (tax rates) are reported in appendix C.

3.2.2.3 Primary Nonferrous Smelters. Primary nonferrous smelters include copper, lead, and zinc smelters. Each has a unique process operation that generates emissions at several points. Copper smelters emit SO_2 from the roaster (if the plant has one), reverberatory furnaces, and converters. Zinc smelters emit sulfur from the roaster or the roaster-sinterer, depending upon the type of smelting operation. Emissions from lead smelters derive mostly from the sintering operation, while small amounts are generated by blast furnace operation.

The major control techniques for smelters are: sulfuric acid plants, lime and limestone scrubbing, amine absorption, ammonia scrubbing, and sodium sulfite-bisulfite absorption. The relevant control options and their associated efficiencies for each smelter type were determined and are reported in appendix D. Similarly, annualized emission control costs were developed for each relevant option for representative plant sizes; these are also reported in appendix D.

After identification of each smelter, the annualized control costs for the specified control options were developed by interpolation from the previously mentioned cost estimates. By using the same technique previously applied to other process sources, a control option was projected to be implemented if its total annualized costs, less the value of recovered sulfur, were less than the tax payments implied in the absence of the device. Also, the results were aggregated for each smelter, across smelters for each nonferrous metals industry, and finally across all primary nonferrous sources. The aggregate of projected emissions reductions versus total annualized control costs and versus marginal costs (tax rates) is shown in appendix D.

3.3. Cost of Control Functions

A tax on sulfur emissions is expected to induce firms to control emissions to the level where the sum of the annualized emissions control costs and tax payments is minimized. Cost minimization is achieved by selecting the level of emissions reductions at which the incremental or marginal cost of control equals the tax rate. Projections of the effectiveness and costs of a tax on sulfur emissions depend, therefore, on the control alternatives assumed to be available, and their costs and effectiveness in reducing emissions. Extensive reviews of published studies and private communications with EPA and other knowledgeable sources have been conducted in order to identify the sulfur control alternatives likely to be available by 1978, and their costs and sulfur removal efficiencies. The alternatives selected and costed are presented in appendixes A through E. These alternatives have been costed for controlling sources of various sizes and process configurations to estimate cost functions for each source. A national listing of the major source of sulfur emissions (953 steam-electric power plants, 50 area sources (States), 263 petroleum refineries, 183 sulfuric acid plants, and 28 primary nonferrous smelters) and the process configuration of each has been used in order to conduct a plant-by-plant analysis.

The long run* total and marginal costs of functions, combined for all major sources under consideration, are shown in figures 3 and 4, respectively. These functions are plotted from analytical results of the emissions tax response model. The total cost function (LTC) increases at an increasing rate reflecting the higher costs of controlling smaller plants, the higher cost per ton of sulfur removal at high control efficiencies, and the price premiums for low sulfur fuels. The marginal cost function (LMC), being the first derivative of the total cost function, also increases at an increasing rate throughout the range of emissions reductions presented.

3.4 Effectiveness

The effectiveness of the tax is defined, for the purposes of this study, as the reduction in sulfur emissions that would be induced by a tax on sulfur emissions. The response of the emissions sources to the tax is a function of the cost of control and the tax rate. This analysis has been conducted in 5-cent increments for tax rates from 0 to 30 cents per pound of sulfur emitted.

In the absence of an emissions tax and without the application of any emissions standards except those applicable to new sources, sulfur emissions in 1978 are projected to be about 20 million tons anually from these major sources (see table 4). Eighty-five percent of these emissions would derive from fuel combustion sources. Since the projected rates of uncontrolled emissions from these sources require data on fuel demand, supplies, and prices by sulfur content (see appendix A) (all of which are difficult to project accurately), these projections of the uncontrolled emissions of fuel combustion sources should be cautiously interpreted.

The combined responses to the tax of all the major sources are provided in figure 5 and table 5. For small taxes of 1 to 10 cents per pound of sulfur, large reductions in sulfur emissions are projected. These projections hinge on RTI's cost estimates which indicate, for example, that at a marginal cost of sulfur removal of 10 cents per pound for all plants, the aggregate of all sulfur emissions sources would reduce emissions by

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*The "long run" is a time period long enough for firms to order and install control equipment or negotiate fuel contracts. It has been assumed that such adjustments can be made by 1978.

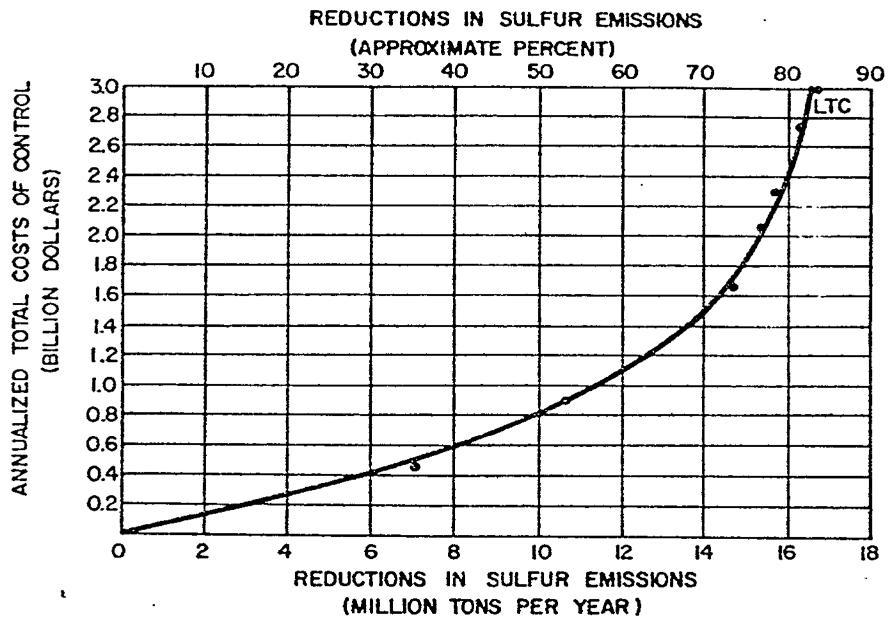

Figure 3. Total cost* of reductions in sulfur emissions from all major sources combined--l978 (*cost does not include emissions tax payments) (Source: Research Triangle Institute).

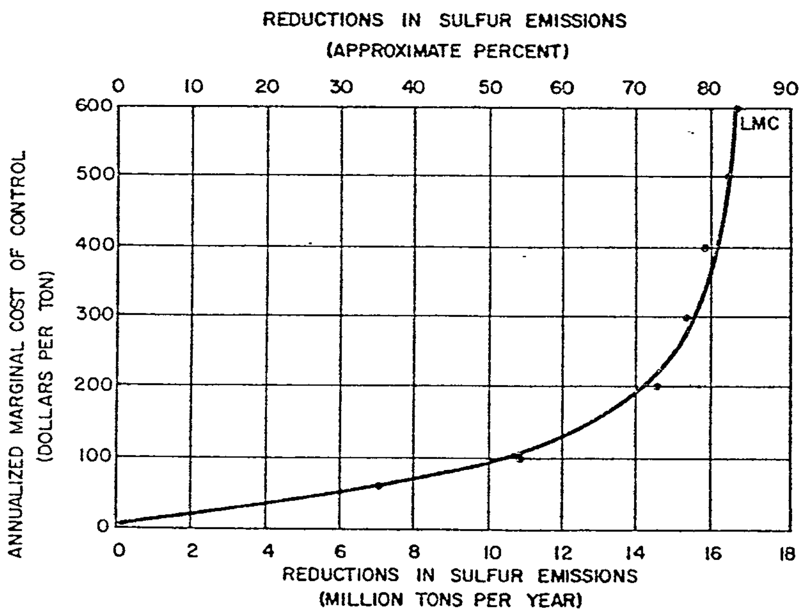

Figure 4. Marginal cost* of reductions in sulfur emissions from all major sources combined--l978 (*cost does not include emissions tax payments) (Source: Research Triangle Institute).

Table 4. Projected sulfur emissions from major sources--1978*

Source	Annual sulfur emissions (thousand tons of sulfur)	Distribution (percent)
Steam-electric power plants	11,396	57.3
Area sources	5,679	28.6
Petroleum refineries	772	3.9
Sulfuric acid plants	376	1.9
Primary nonferrous smelters	1,650	8.3
Total from all sources	19,873	100.0

*Assuming only controls required by the New Source Performance Standards.

Source: Research Triangle Institute.

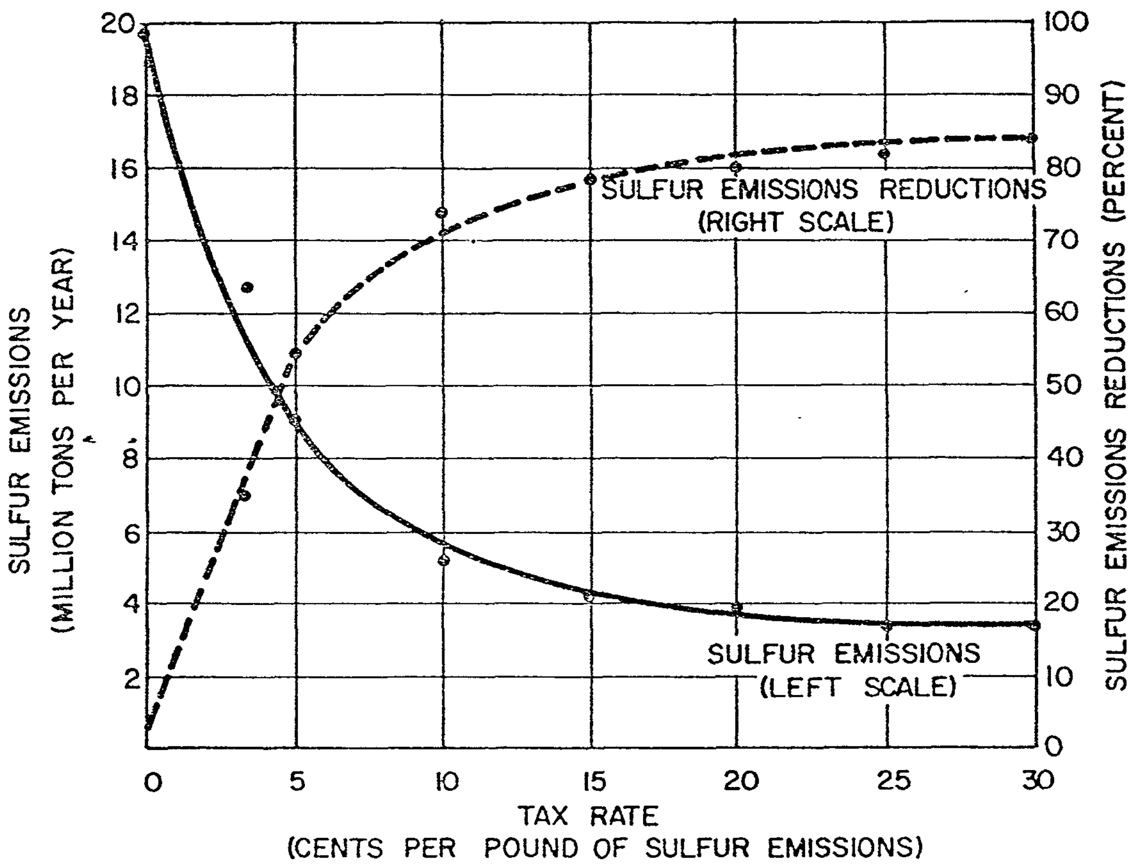

Figure 5. Effectiveness of a tax on the sulfur emissions from all major sources combined--1978 (Source: Research Triangle Institute).

Table 5. Projected response of all major sources combined to a national tax on sulfur emissions--1978

Emissions source	Emissions (thousand tons)	Reductions in emissions from zero tax (thousand tons)	Total annual costs (thousands)	Annualized control costs (thousands)	Annual tax payment (thousands)
Tax rate: 5 cents per pound of sulfur emitted					
Steam-electric utilities	5,159.0	6,237.0	$1,171,808	$ 655,881	$ 515,928
Area sources	2,854.7	2,822.8	466,497	181,026	285,472
Petroleum refineries	608.1	163.7	66,403	5,596	60,808
Sulfuric acid plants	385.4	0.0	38,546	0	38.546
Primary nonferrous smelters	278.9	1,371.5	85,098	57,206	27,892
Total from all sources	9,286.1	10,595.0	$1,828,352	$899,709	$ 928,646
Tax rate: 10 cents per pound of sulfur emitted					
Steam-electric utilities	2,961.8	8,434.2	$1,774,661	$1,182,231	$ 592,432
Area sources	1,494.3	4,183.2	654,265	355,391	298,874
Petroleum refineries	537.5	234.0	122,276	14,730	107,546
Sulfuric acid plants	96.7	288.8	59,410	40,074	19,335
Primary nonferrous smelters	110.6	1,539.9	98,345	76,233	22,112
Total from all sources	5,200.9	14,680.1	$2,708,957	$1,668,659	$1,040,299
Tax rate: 15 cents per pound of sulfur emitted					
Steam-electric utilities	2,277.7	9,118.2	$2,215,069	$1,531,655	$ 683,417
Area sources	1,383.1	4,296.5	796,647	382,344	414,306
Petroleum refineries	509.6	261.9	174,631	21,670	152,961
Sulfuric acid plants	60.9	324.4	66,797	48,486	18,311
Primary nonferrous smelters	94.8	1,555.6	108,837	80,386	28,451
Total from all sources	4,324.1	15,556.6	$3,361,981	$2,064,542	$1,297,446
Tax rate: 20 cents per pound of sulfur emitted					
Steam-electric utilities	1,948.2	9,447.7	$2,589,688	$1,810,295	$ 779,394
Area sources	1,377.2	4,300.3	934,526	383,646	550,881
Petroleum refineries	499.6	271.9	225,008	25,056	199,952
Sulfuric acid plants	48.7	336.7	72,018	52,525	19,492
Primary nonferrous smelters	81.4	1,569.1	117,873	85,323	32,550
Total from all sources	3,955.1	15,925.7	$3,939,113	$2,356,845	$1,582,269
Tax rate: 25 cents per pound of sulfur emitted					
Steam-electric utilities	1,599.5	9,796.5	$2,911,882	$2,112,043	$ 799,836
Area sources	1,115.2	4,562.2	1,059,893	502,214	557,680
Petroleum refineries	497.2	274.4	274,856	26,161	248,696
Sulfuric acid plants	47.4	337.9	76,831	53,110	23,722
Primary nonferrous smelters	79.6	1,570.9	125,894	86,103	39,791
Total from all sources	3,338.9	16,541.9	$4,449,358	$2,779,636	$1,669,725
Tax rate: 30 cents per pound of sulfur emitted					
Steam-electric Utilities	1,432.1	9,963.9	$3,186,375	$2,326,992	$ 859,384
Area sources	1,030.9	4,646.6	1,164,706	546,153	618.554
Petroleum refineries	496.4	275.3	324,519	26,681	297,837
Sulfuric acid plants	46.9	338.5	81,548	53,392	28,158
Primary nonferrous smelters	79.2	1,571.2	133,820	86,288	47,532
Total from all sources	3,085.5	16,795.5	$4,890,980	$3,039,506	$1,851,477

Source: Research Triangle Institute.

more than 70 percent. Beyond tax rates of 10 cents, only small additional amounts of reduction are induced. For example, a 30-cent tax would only yield an additional 10-percent reduction.

3.5 Costs

The costs of sulfur emissions tax strategy would consist of the tax payments plus the costs of control, both of which would initially be paid by the polluting sources. To the industry, there is no significant conceptual difference in these costs since they both become part of the costs of production and must either be absorbed in profits or shifted to customers and, ultimately, to consumers. From the perspective of society, however, the difference between the tax payments and the costs of control is significant. In a full employment economy, allocation of resources for production of emissions control equipment implies a reduction in the production of other goods and services. The tax payments, however, are transfers of income from industry to government, and imply no reduction in production.

The total annualized costs to all major sources together are shown in figure 6. Since the tax induces emission control, the total costs of the tax increase at a decreasing rate.

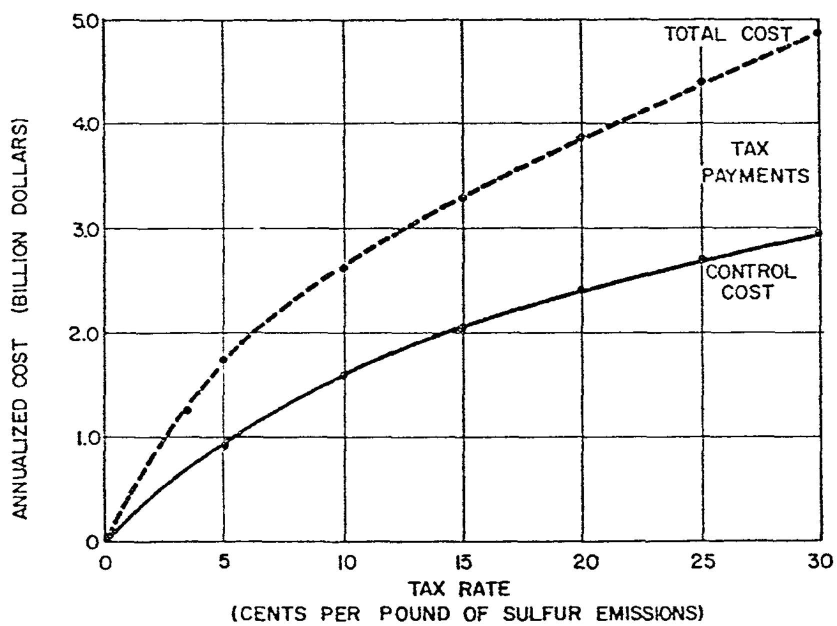

Figure 6. Total costs induced by a tax on the sulfur emissions from all major sources combined--1978 (Source: Research Triangle Institute).

3.6 Tax Revenues

From the perspective of government, the tax payments by the polluting sources are revenues. These revenues are shown in figure 7 for all tax rates under consideration. At a tax rate of 10 cents, revenues would be about $1 billion annually or about $5 per capita. A tax of 30 cents would almost double revenues from those projected for the 10-cent tax. It should be noted, however, that the net increase in government revenues would not be the full amount of the emissions tax since emissions tax payments would reduce the firm's income tax liability by the amount equal to the tax rate times the total emissions tax liability. For example, if the corporate tax rate were 50 percent, the net increase in government revenues would be one-half of the total emissions tax proceeds.

3.7 Cost-Benefit Analysis.

Ideally, as discussed in chapter 2, the application of emissions taxes for environmental quality management would not be based on cost-effectiveness but rather on cost-benefit analyses. Data on the nature of the benefit

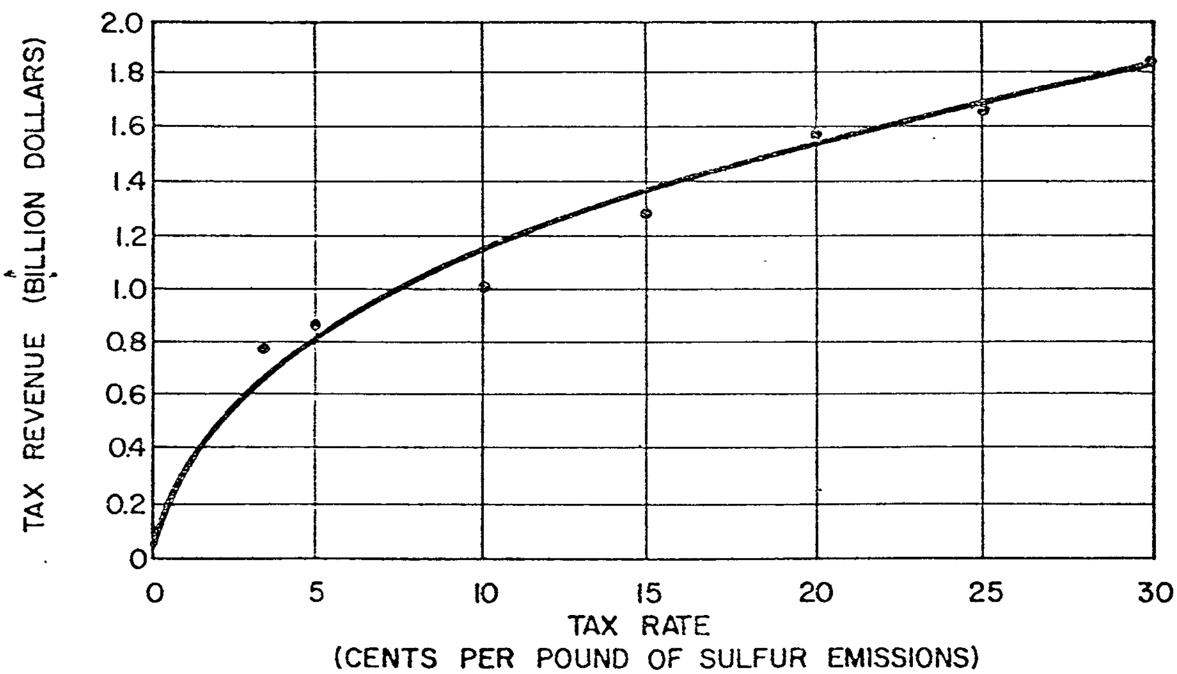

Figure 7. Tax revenues from a tax on sulfur emissions from all major sources combined--1978 (Source: Research Triangle Institute).

function for sulfur emissions reductions are.currently quite incomplete. However, estimates developed from a recent compilation and evaluation of the damages of residential property, materials, health, and vegetation from the presence of sulfur oxides in the atmosphere for 1968 indicate that the national cost averaged about $500 per ton of sulfur*. The authors of that study point out a number of limitations in the data, but conclude: (1) these are the best estimates currently available, and (2) for the present it must be assumed that the marginal and average benefits (or avoidance of damages) are equal. Using their estimate for 1968 of $500 per ton and assuming that the damages in 1978 are the same per ton, a tax of 25 cents would equate the costs and benefits of control at the margin. It should be noted that the benefits would vary from region to region as would the costs.

3.8 Impacts on Consumer Prices

It is beyond the scope of this study to provide any extensive analysis of the likely incidence of the sulfur tax. However, a preliminary analysis is possible.

The effect of a tax on sulfur emissions (or, for that matter, of regulation on emissions) will be an increase in the marginal costs of production for every affected firm in the industry whose emissions are being taxed. Since the horizontal summation of the marginal cost curves of these firms yields the industry supply curve (assuming the absence of external economies or diseconomies and a perfectly competitive industry), the effect of a tax is to shift the industry supply curve upward and to the left. Assume, for the sake of expositional simplicity, that the sulfur tax implies a uniform increase (t) in the marginal costs of producing Q, an output whose production generates sulfur emissions. One can then depict the effect of the tax as an upward shift in the supply schedule of the subject industry by the constant amount of the uniform tax-induced increase (t) in marginal costs. The supply schedule shifts from S to S + t in figure 8. Since the price and output of Q are determined by the intersection of the supply and demand schedules, the sulfur tax would induce a reduction in output from Q_0 to Q_1, and an increase in the price per unit of Q from P_0 to P_1.

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*Larry Barrett and Thomas Waddell, Cost of Air Pollution Damage: A Status Report, Environmental Protection Agency, Research Triangle Park, N.C., 1973, p. 61.

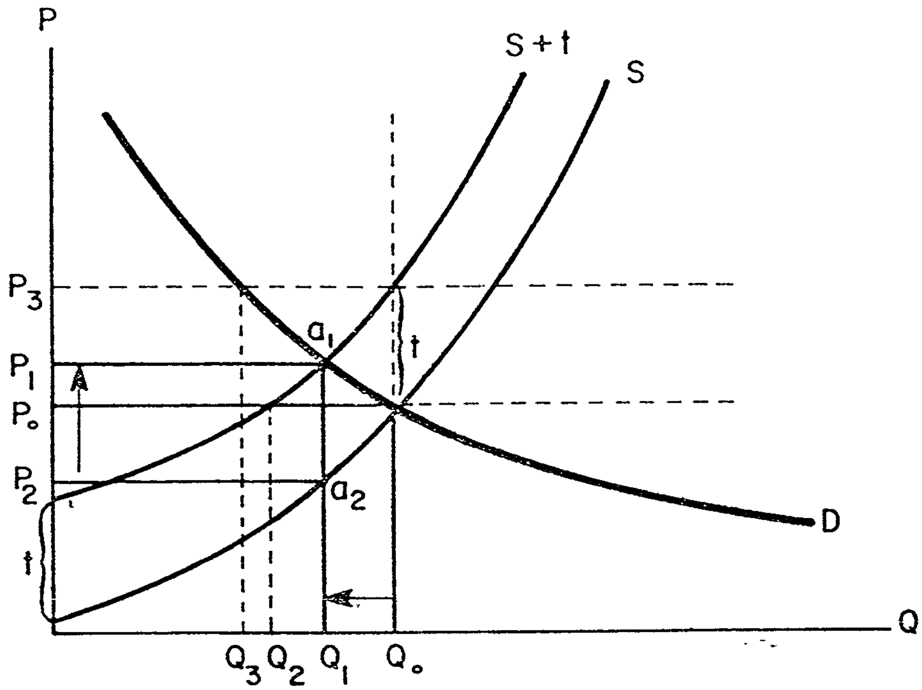

Figure 8. The incidence of a sulfur emissions tax.

The importance of this analytical device derives from the obvious fact that the percentage increase in the price of the product whose output generates pollution depends critically upon the slope of both the supply and demand schedules. The demand schedule, in general, will become more horizontal (vertical) according to whether there are (are not) good substitutes for Q and according to whether the product constitutes a large (small) share of the average consumer's budget. The supply schedule, on the other hand, becomes more horizontal (vertical) according to whether inputs to the production of Q can (cannot) be easily shifted into the production of other products.

As the supply and demand schedules are depicted in figure 8, only $(P_1 - P_0)/t$ of the uniform increase in the per unit cost of Q production is passed on to consumers. The remainder, $(P_0 - P_2)/t$, is absorbed by producers; they are forced to forego the profits (or rents) that would otherwise accrue to them. If all of the increase in costs is accounted for by tax payments, the government would collect emissions tax revenues equal to the area $P_1a_1a_2P_2$ during each period.

Now, observe the extreme possibilities. Assume that the demand schedule continues to be represented by D in figure 8 but that it is virtually impossible to shift inputs out of Q production. The result would be a vertical supply schedule at the quantity Q_0. All of the emissions tax-induced costs would be absorbed by producers as forfeited profits. The price would remain at P_0. At the opposite extreme, assume that all inputs to Q production are supplied to producers in unlimited quantities at constant prices (perfectly elastically supplied). The consequence is a horizontal supply schedule. All of the costs of the emissions tax would devolve onto the final consumers. Prices would rise by the full amount of the tax-induced costs (to P_3) and consumption would fall (to Q_3).

A similar analysis of extreme behavior in demand is possible by assuming the supply schedule remains stable at S and by allowing the demand schedule to vary in slope. If, for example, there are nearly perfect nonpolluting substitutes for Q, consumers will not tolerate any increase in its price; the demand schedule will be perfectly elastic (horizontal). Producers will have to absorb all of the cost imposed by the tax, and output will fall to Q_2 as the marginal producers of Q go out of business. On the other hand, if the consumer has no ready access to substitutes for Q or if Q is a very small share of his budget (so that price increases go virtually unnoticed), the demand schedule is likely to be perfectly inelastic (vertical) at Q_0. This would enable producers to shift the entire burden of the tax to consumers. The price of Q would rise to P_3 while the output would remain constant at Q_0.

An initial analysis of these price effects can be accomplished by assuming what, for consumers, is a worst-case situation--that the entire cost increase attributable to the tax is passed on to them. This analysis combines the assumption that inputs to the affected industry are relatively mobile (supply is elastic) while consumer preference for that product is relatively inflexible, in the face of price changes. Allowing these assumptions, RTI was able to adapt its previously developed model to project the consumer price increases implied by increases in industry production costs.

In a previous study for EPA*, RTI developed a model for projecting the impact on consumer prices of increases in industry costs. This model utilizes

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*D. A. LeSourd and F. G. Bunyard, eds., Comprehensive Study of Specified Air Pollution Sources to Access the Economic Impact of Air Quality Standards, EPA contract No. 68-02-0088, Research Triangle Institute, Research Triangle Park, N. C., August 1972.

the 1963 national input-output table (at the 364 sector level) plus a disaggregated consumer demand sector with 80 subcategories of personal consumption expenditures.*

The limitations of input-output analysis are well known and the implications of using a 1963 structure of product to represent an economy 15 years hence are obvious and need not be further discussed here. Price increases may take many forms such as reductions in quality or service; they may also be distributed discriminately to different customers of the industry's products. Suffice it to say that the model can only provide a first approximation of what is a very complex and not well understood process. Nevertheless, taken in that light, the model does provide a useful appraisal of the possible price impacts of a tax on sulfur emissions.

Table 6 shows the initial price increases for selected tax rates, on a percentage basis using 1970 product prices as the base; these increases are projected for each of five sources assuming that they shift the entire cost of the tax in the form of higher product prices. All annualized industry costs associated with the tax or with pollution abatement were halved to account for the effect of government cost-sharing through the corporation tax structure. See appendix F.

Table 6. Projected initial price increases resulting from a tax on sulfur emissions (percent increase over 1970 average prices)

	Tax rate (cents per pound of sulfur emitted)					
Source	5	10	15	20	25	30
Steam-electric	2.2	3.4	4.2	4.9	5.0	6.2
Petroleum refining	0.1	0.2	0.3	0.4	0.5	0.6
Sulfuric acid production	2.6	4.0	4.5	4.9	5.2	5.5
Primary copper smelting	1.0	1.1	1.2	1.3	1.4	1.5
Primary zinc smelting	0.9	1.4	1.8	1.9	2.0	2.1
Primary lead smelting	0.7	0.8	0.9	1.1	1.2	1.3

Source: Research Triangle Institute.

*This index is a Paasche-type measure of consumer price changes, since the current composition of expenditures is used to weight the components of the index.

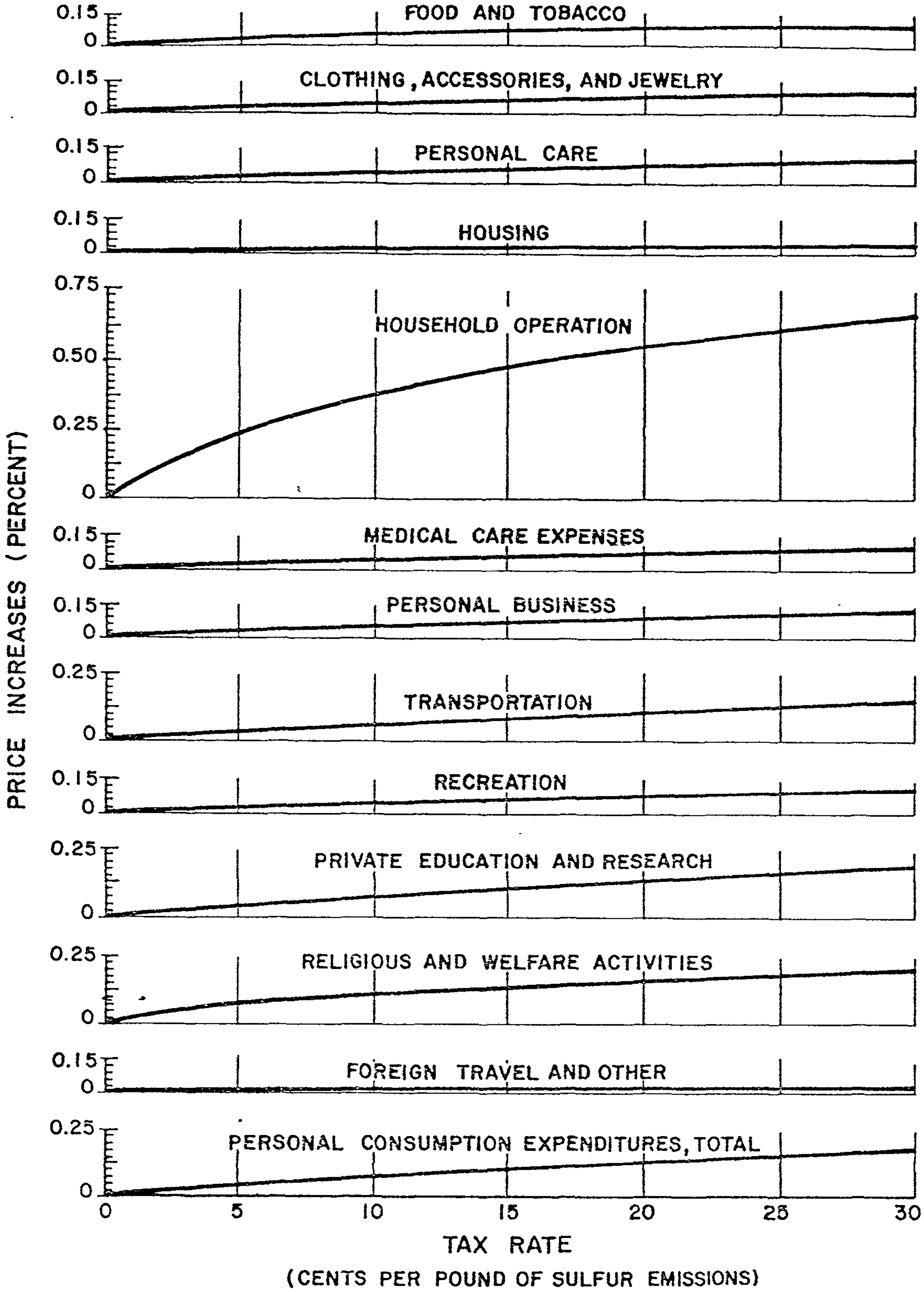

Figure 9. Projected impact on consumer prices of a tax on the sulfur emissions from all major sources--1978 (Source: Research Triangle Institute).

Figure 9 depicts the effect of the intermediate goods price increases (table 6) on final product prices. Among the six identified intermediate product categories, higher electricity prices would have the most significant impact on consumer prices. For the highest tax rate examined (30 cents), the increase in consumer prices would be about 0.15 percent (fig. 9, bottom panel). The percentage price increases in figure 9 are small relative to those in table 6 since the products in the table are only a few of the intermediate goods used to produce the final goods and services in the figure. The expenditure category that includes relatively more of these intermediate goods and that therefore would experience a larger percentage increase in prices is household operation. The other expenditure categories are affected to a much smaller extent. Overall, it seems apparent that the sulfur-tax-induced increases in consumer prices would not be substantial.